WHITE PAPER

BEAMWATCH ENHANCEMENTS

IMPROVEMENTS IN THE BW-NIR-130 AND BW-PLUS-45

Yaakov Pechman, Oleg Zinoviev

This white paper explores the evolution and improvements of the noninvasive BeamWatch family of products. These enhancements are designed to augment the measurement capabilities of the products. Furthermore, they address the burgeoning demands in high-power applications that rely on visible wavelength lasers.

The improvements in the optical componentry and image preprocessing of the BeamWatch family of products enable:

- Accurate measurement of beams throughout the NIR wavelength spectrum, ranging from 950nm to 1100nm.
- Extended BeamWatch measurement capabilities to include visible wavelengths from 420nm to 635nm.
- Measurement of beams with narrower waists compared to earlier models of BeamWatch.

Legacy BeamWatch Products

The foundational BeamWatch measurement technique is anchored in analyzing the Rayleigh scatter of a laser beam along the length of the caustic near the waist. Sophisticated optical components and image preprocessing techniques make this possible.

Optical Components

- A mirror system diverts the image into distinct X and Y components, thereby creating XZ and YZ projections that enable the characterization of the beam for both axes simultaneously.
- A telecentric lens (with 1:1 or 3:1 image reduction, depending on the model) creates an orthographic projection onto the camera.
- A camera captures and transfers the resulting image of the Rayleigh scatter to the PC.

Image Distortion and Restoration

The resolution of the telecentric lens is inherently limited by distortion factors such as the diffraction limit as well as the design of the lens itself. Mathematical functions can be defined to quantify the specific distortion of the telecentric lens.

The resolution of the camera is limited by its pixel-size as well as distortions introduced by pixel crosstalk. Here too, a mathematical function can be defined to quantify the specific distortion of the camera.

In the legacy BeamWatch products the overall system distortion was determined experimentally, creating a composite function for both the lens and the camera. Using this mathematical function, the original beam can be restored using deconvolution algorithms in real-time, a procedure termed “preprocessing.”

LEGACY BEAMWATCH PRODUCTS

Please Note: Definition of algorithms used in the preprocessing step are designed to provide higher quality data to the measurement engine. There is no direct dependency between this preprocessing phase and the specific algorithms employed within the result calculations.

Image Correction Implementation

The original implemented image correction procedure was based on direct measurement at a wavelength of 1070nm. For wavelengths that deviated from 1070nm, after the preprocessing was completed a wavelength specific correction factor was applied.

Development of the BW-NIR-130 and BW-PLUS-45

Impetus

There are continuously increasing trends in high-power applications, especially those utilizing visible wavelength lasers and/or complex beam structures. These trends have necessitated the introduction of advanced beam profiling products. The primary BeamWatch enhancements include the following:

- A new camera was introduced to mitigate pixel crosstalk and enhance resolution.
- The wavelength dependent corrections were recalculated directly from the telecentric lens models, and the camera pixel size was characterized separately.
- A focus offset adjustment was introduced to compensate for the chromatic aberration of the telecentric lens.
- Modifications were made to consider the magnification variation due to focus shifts.
- A delay glass insert was introduced to compensate for the chromatic aberration of the telecentric lens which enables accurate optical alignment for the 420nm to 635nm range of wavelengths.
- A more accurate means was employed for initial device alignment.

Camera Replacement

The new camera provides less crosstalk between pixels in the NIR range compared to the original camera. As such, there is less distortion in the image, resulting in better resolution. The camera distortion correction algorithms were modified accordingly, which enables the device to measure minimum spot sizes of 130μm and 45μm, replacing the previous minimum spot sizes of 155μm and 55μm.

DEVELOPMENT OF THE BW-NIR-130 AND BW-PLUS-45

Wavelength Dependent Distortion

- Diffraction limit of the telecentric lens is a function of the wavelength.
- Due to chromatic aberration, the focal length of the telecentric lens on the camera changes based on wavelength.
- Due to the change in focal length, the effective magnification factor of the telecentric lens changes as well.

Image Correction Algorithms

A wavelength specific image correction algorithm is now defined from simulated models of the telecentric lens, and the camera distortions are defined separately. These algorithms are enhanced to account for situations where the laser has shifted out of the optimum focus position.

Focus Offset Adjustment

The BeamWatch alignment procedure aligns a 1070nm beam focus spot to the center of the camera as seen through the telecentric lens. Different wavelengths focus at different locations. This is adjusted by applying a corrective offset factor that is wavelength dependent. The software alignment crosshairs have been updated to mark the location of best focus for the entered wavelength, not necessarily the center of the field of view.

Magnification Variation

The lens magnification at 1070nm is determined during the BeamWatch device calibration. This value will vary slightly as the beam wavelength changes. The behavior has been modeled and encapsulated in the software to automatically adjust the magnification value based on the entered wavelength.

Delay Glass and Visible Wavelength Support

These device improvements apply to the 950nm to 1100nm wavelength range, but visible wavelengths shift the focus too far to be aligned properly without different optics. To compensate for this, a delay glass is inserted into the BeamWatch Plus product to change the central alignment wavelength from 1070nm to 515nm. With the delay glass inserted, the BeamWatch is able to measure wavelengths from 420nm to 635nm.

Initial Alignment

The alignment procedure for the BeamWatch camera and optical system has been refined to position the X and Y views more accurately. This procedure ensures the optical path of both views are identical and reduces the appearance of artificial astigmatism.

COMPARISONS

Comparisons

A 1070nm beam with a waist width of 128um was measured with the BW-NIR-155, the BW-NIR-130, and a camera-based beam profiler utilizing BeamGage. The measured Rayleigh Length, Waist Width, Divergence, and M^2 values are reported along with the errors. The table below shows the improvements in the newer BeamWatch model, regardless of the selected beam width measurement method.

	BeamPeek BG + Z-stage	BW-NIR-130 (new camera)		BW-NIR-155 (old camera)	
	D4σ	D4σ	D4σ-Iterative	D4σ	D4σ-Iterative
Power, W	67	515		500	
Zr, mm	10.82	11.08	10.92	12.39	12.24
Zr Error vs. BG	--	2.36%	0.92%	14.46%	13.07%
W0, µm	128	127	130	143	148
W0 Error vs. BG	--	-0.41%	1.95%	11.95%	15.67%
theta, mrad	11.79	11.48	11.92	11.54	12.07
theta Error vs. BG	--	-2.63%	1.10%	-2.12%	2.37%
M^2	1.106	1.071	1.139	1.209	1.309
M^2 Error vs. BG	--	-3.16%	2.98%	9.31%	18.35%

Conclusions

The BeamWatch product lineage has witnessed extensive enhancements, reflecting the dynamic nuances of the laser industry. A meticulous approach to the algorithms and system chromatic aberrations paved the way for the inception of the BW-NIR-130, tailored for the NIR range (950nm-1100nm). Additionally, the integration of the delay glass insert led to the creation of the BW-PLUS-45 model, which is suitable for both the visible (420nm-635nm) and NIR (950nm-1100nm) wavelength ranges.

Note: The new camera is slightly less sensitive in the NIR wavelength range. This was a tradeoff with the reduction in crosstalk it provides. As such, although the new BeamWatch has better resolution, customers applying the new model to the same application and setup used with a previous model device may require a higher exposure setting or a higher laser power setting to achieve the same signal intensity. At MKS Ophir, we believe the benefits of higher quality measurement and resolution far outweigh this cost.

www.ophiropt.com

Whitepaper_BeamWatch_Enhancements_10/23